OMI Tropospheric NO2 from Lightning in Observed Convective Events

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Introduction

- **Lightning produces ~15% of total NOx emissions.**
- **Most likely global LNOx production is 2 – 8 TgN/yr (Schumann and Huntrieser, 2007, *ACP*).**
- **Most of lightning-produced NOx injected into middle and upper troposphere; important for UT ozone production, especially in tropics.**
- **Previous satellite lightning NO2 (LNO2) analyses: Events: Richter and Burrows (2002); Thomas et al. (2003); Beirle et al. (2004; 2006)**

  Global: Boersma et al. (2005), Martin et al. (2007)
- **This analysis uses OMI tropospheric NO2 to obtain estimates of LNOx production in specific convective events over the Central USA.**

Procedure

- Cases of possible NO2 from lightning (LNO2) downstream of observed storms identified from NASA standard retrieval tropospheric NO2 data sets

- OMI data screened for 100% cloud cover for days of interest

- NO2 profile shapes from cloud-resolved modeling of midlatitude storms with lightning used in estimating appropriate AMFs

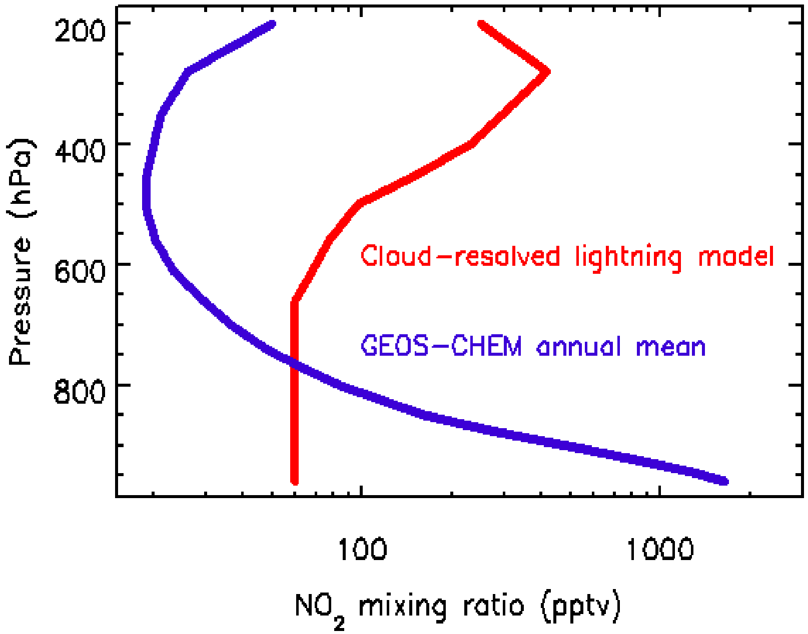
- Background (pollution, soil NOx, lightning from other storms) is removed by subtracting monthly mean

$$LNO2 = (OMINO2_{trop} - OMINO2_{tropMonthlyMean}) \times (AMF_{GEOS\text{-}Chem} / AMF_{lightning})$$

- Estimate LNOx by assuming that LNO2 is 30% of LNOx in 500 – 200 hPa layer.

Procedure (continued)

- Run set of back trajectories starting at 500, 300, and 200 hPa with 1 x 1 degree separation from region of enhanced OMI NO2 from time of OMI overpass, and count upstream NLDN CG flashes in 1 x 1 degree grid boxes. Assume decay rate equivalent to 3.5-day NOx lifetime in UT.
- Obtain vertically weighted average number of upstream CG flashes using vertical profile of LNOx from prior cloud-resolved model simulations.
- Adjust CG flash counts for NLDN detection efficiency of ~90%.
- Scale up the CG flash counts to total flashes using the Boccippio et al. (2001) IC/CG ratio climatology.
- Divide estimates of moles of LNOx in enhanced region by number of total upstream flashes to obtain average moles/flash

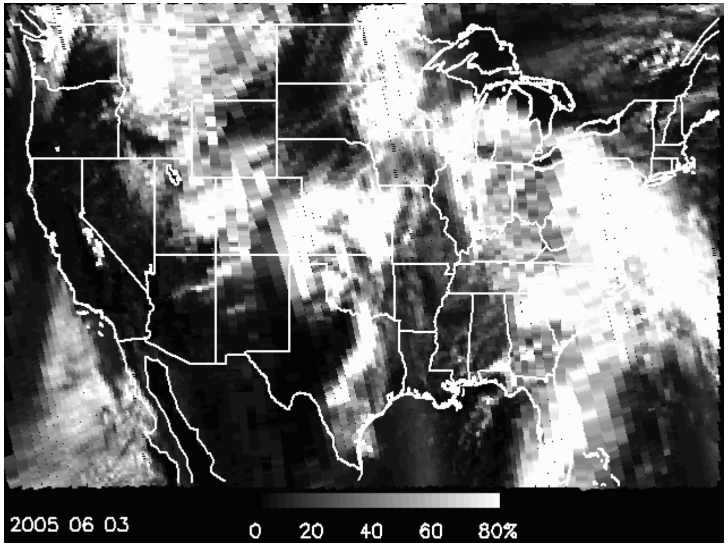


LNO2 profile from UMD Cloud Chemistry Model averaged over simulations for three midlatitude storms

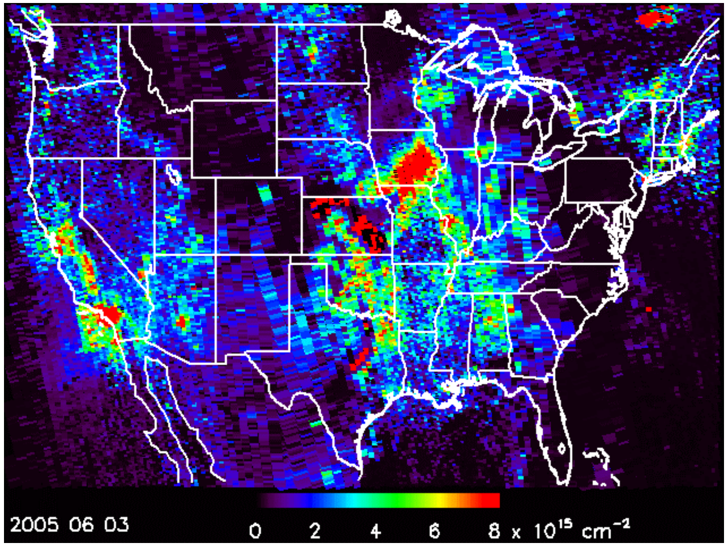
Profile representative of outflow 100 km downwind of storm core

With 40% cloud cover:
AMF with GEOS-Chem
NO2 profile ~ 0.9
AMF with anvil outflow
NO2 profile ~ 2.0

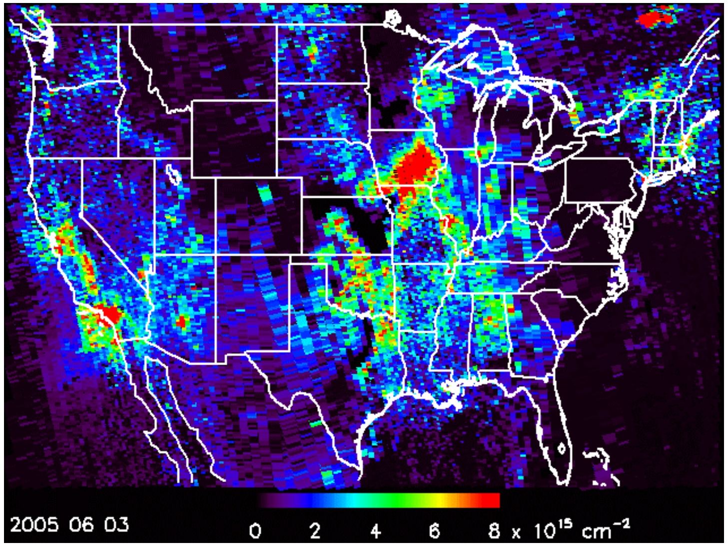
Case 1: June 3, 2005



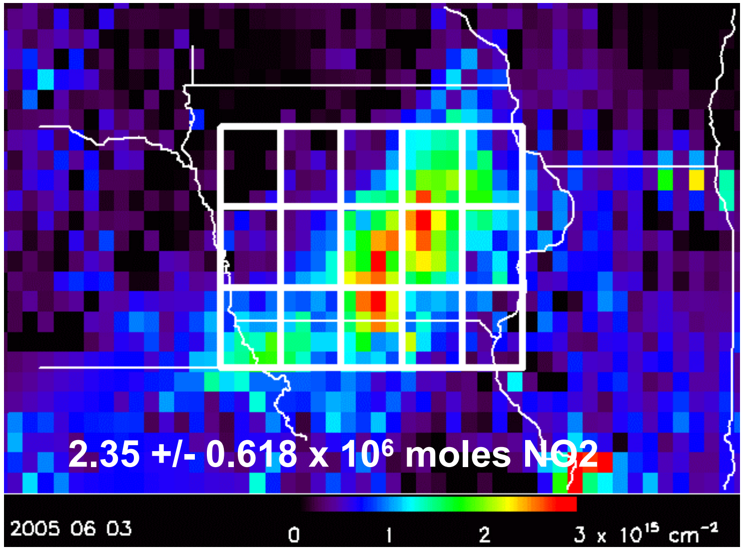
Cloud Cover



Level 2 OMI Tropospheric NO2

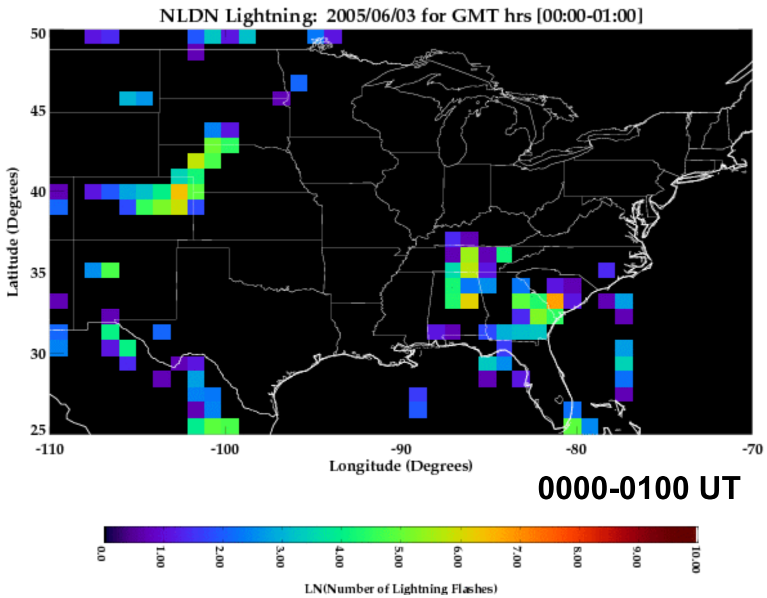


After removal of pixels with 100% cloud cover

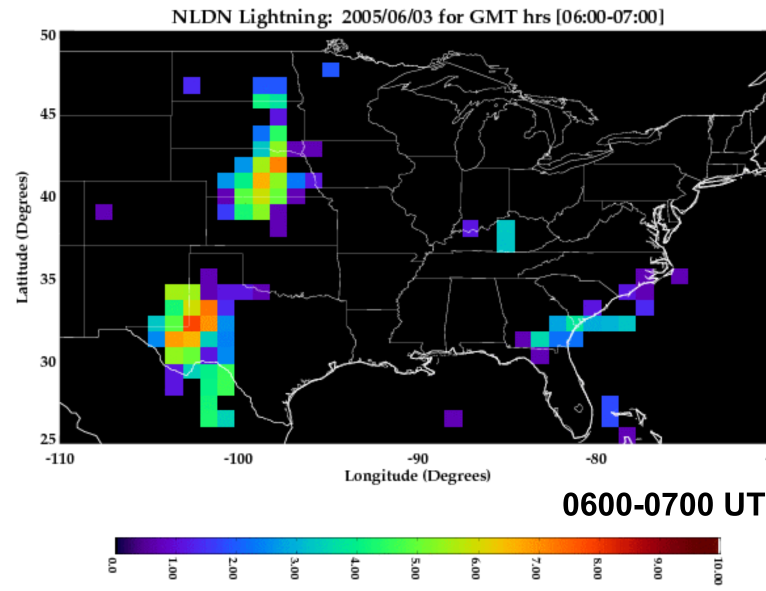


LNO2 on 0.25 x 0.25 degree grid

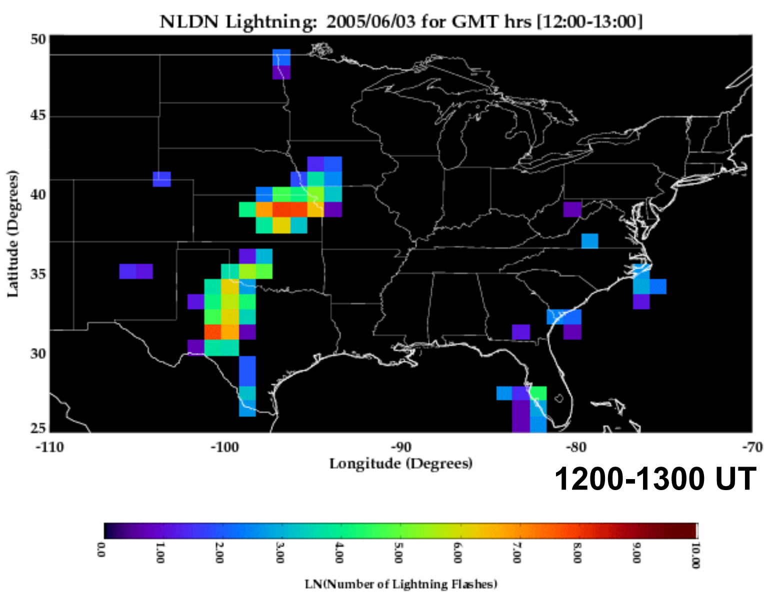
Case 1: June 3, 2005



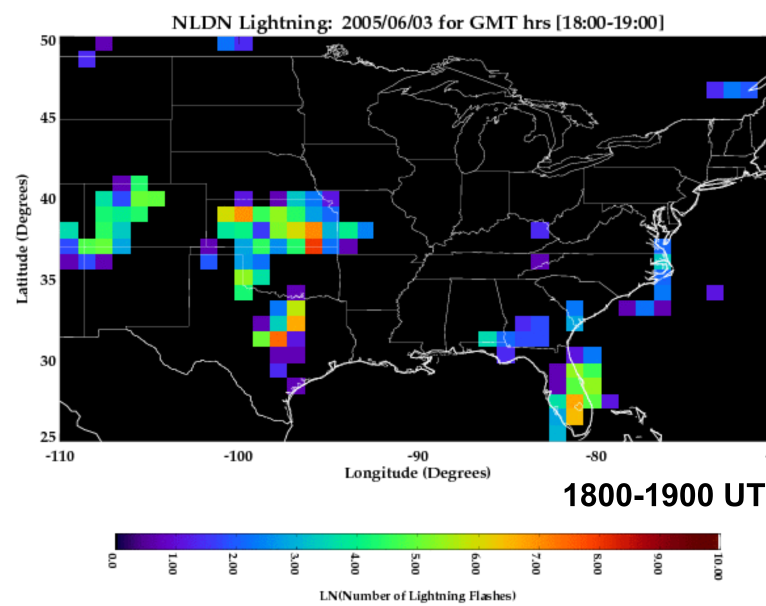
0000-0100 UT



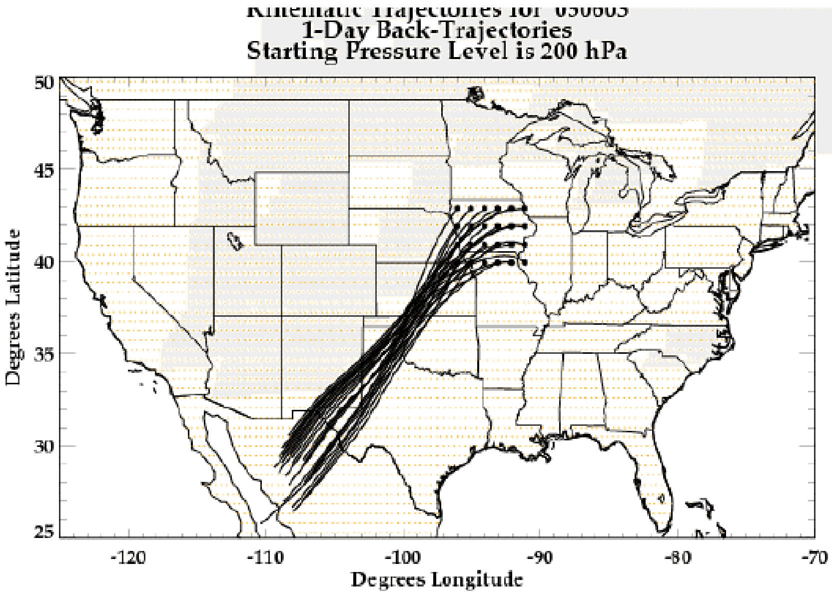
0600-0700 UT

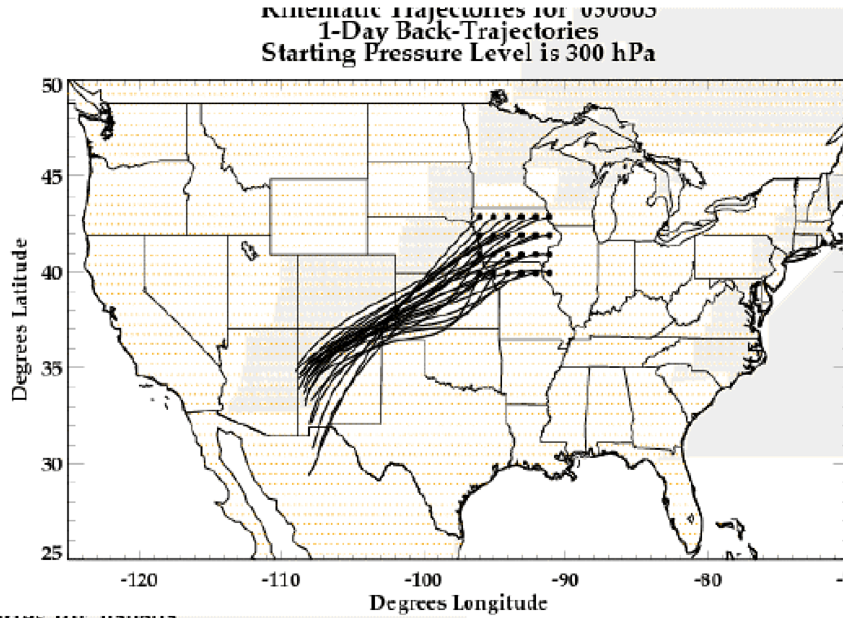


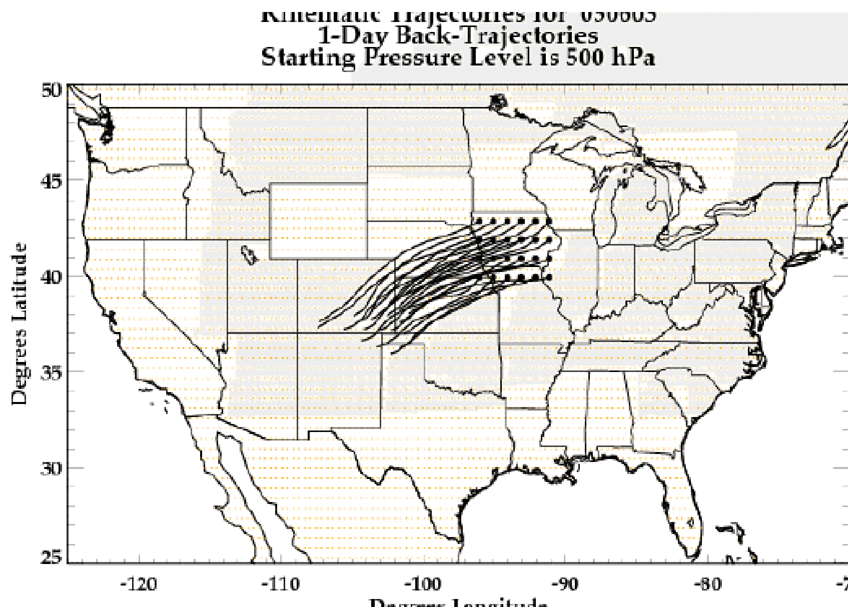
1200-1300 UT



1800-1900 UT


1-Day Back-Trajectories
Starting Pressure Level is 200 hPa
Degrees Latitude
Degrees Longitude


1-Day Back-Trajectories
Starting Pressure Level is 300 hPa
Degrees Latitude
Degrees Longitude


1-Day Back-Trajectories
Starting Pressure Level is 500 hPa
Degrees Latitude
Degrees Longitude

Case 1: Calculations

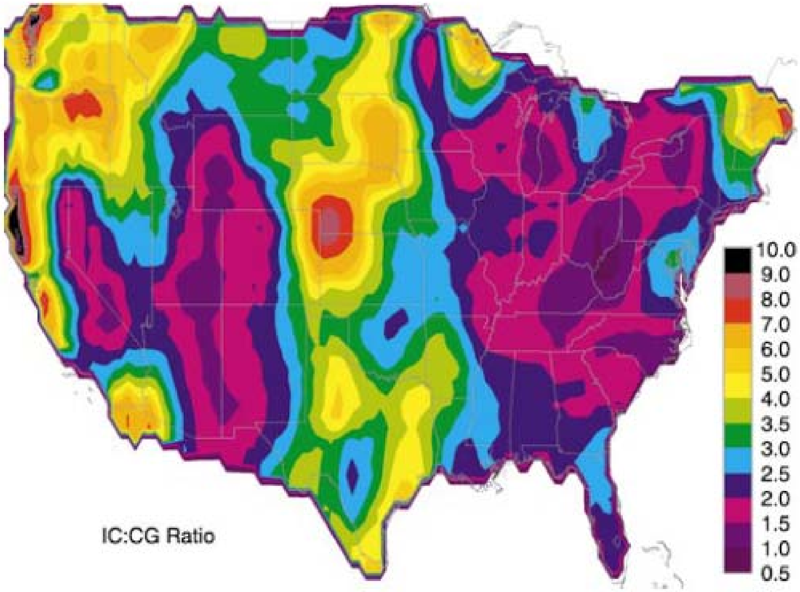
Upstream CG Flashes:

500 hPa	1724
300	3031
200	1750

Using LNOx mass profile from midlatitude cloud-resolved simulations:

Vertically mass-weighted upstream CG flashes = 2163

Scaling up to total flashes using detection efficiency of 90% and mean IC/CG ratio = 6 for region of upstream flashes yields 16,827 flashes



Boccippio et al., 2001

Case 1: Calculations

Scaling up to NOx from NO2:

2.35 x 10^6 moles NO2 x 1 mole NOx/0.3 moles NO2

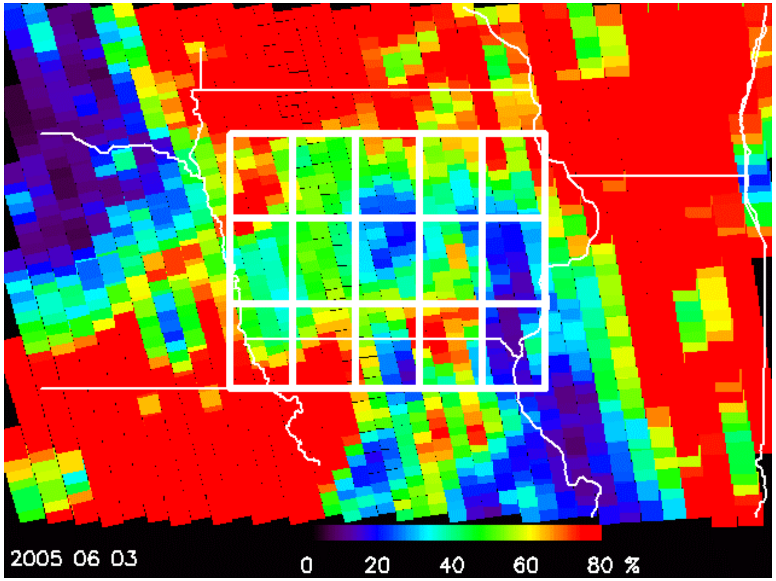
= 5.47 x 10^6 moles NOx

Estimating average moles NOx per flash:

7.83 x 10^6 moles NOx / 16827 flashes

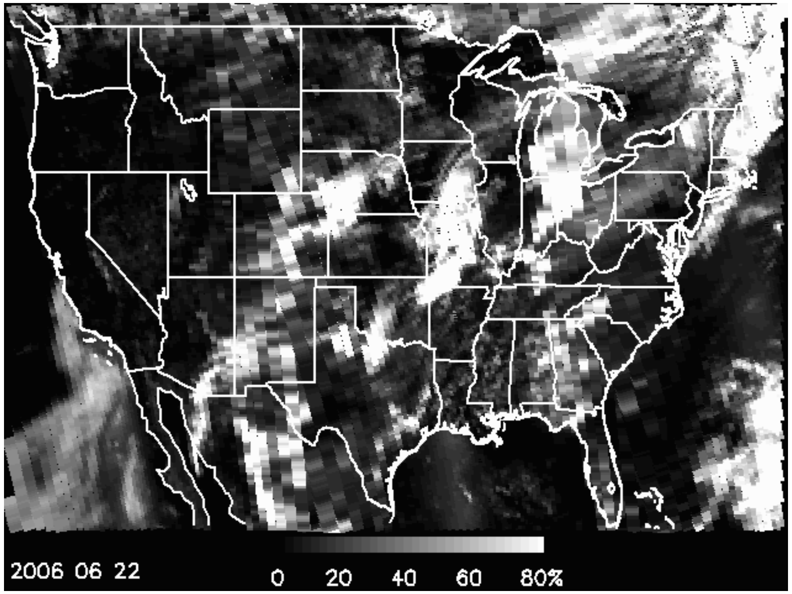
= 465 +/- 122 moles NOx/flash

Large source of uncertainty

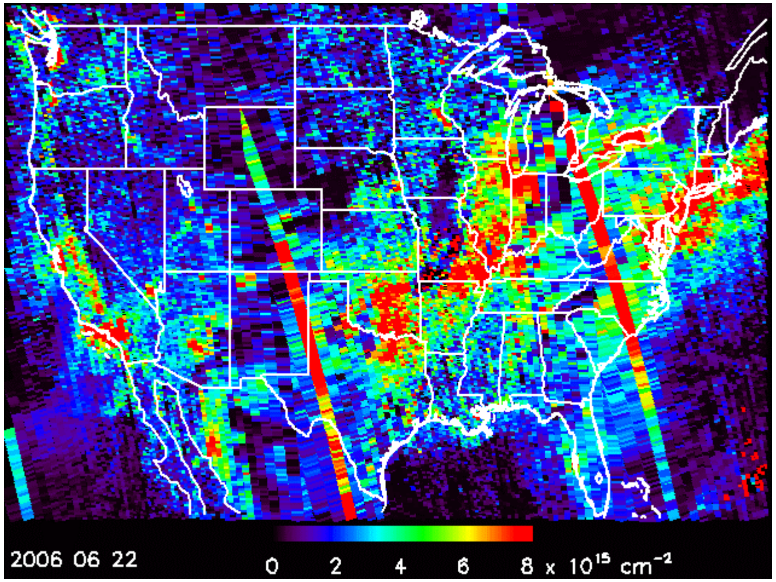


Effective Cloud Fraction

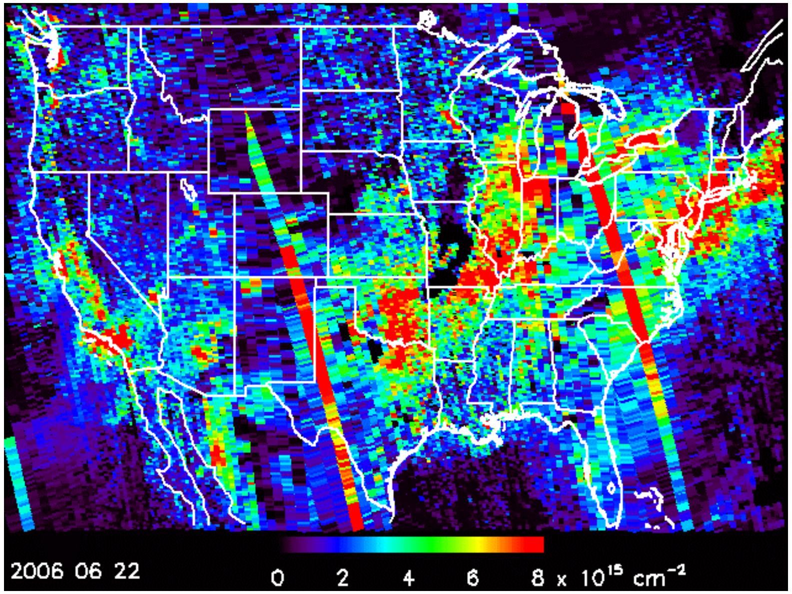
Case 2: June 22, 2006 - Oklahoma



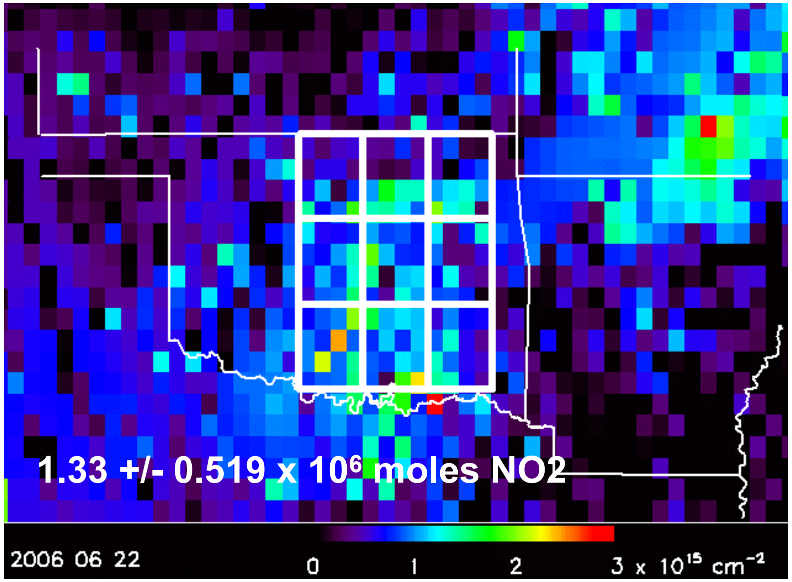
Cloud Cover



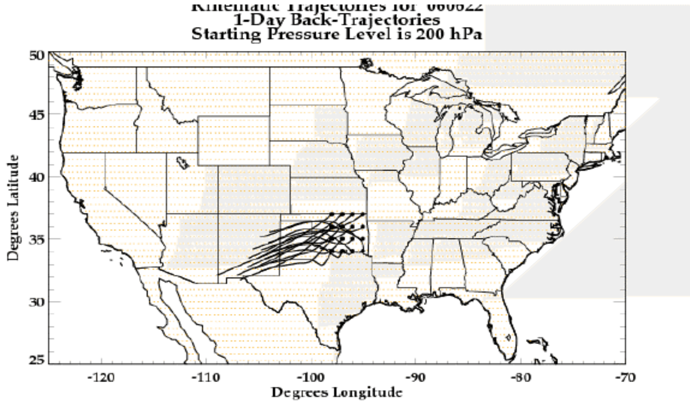
Level 2 OMI Tropospheric NO2

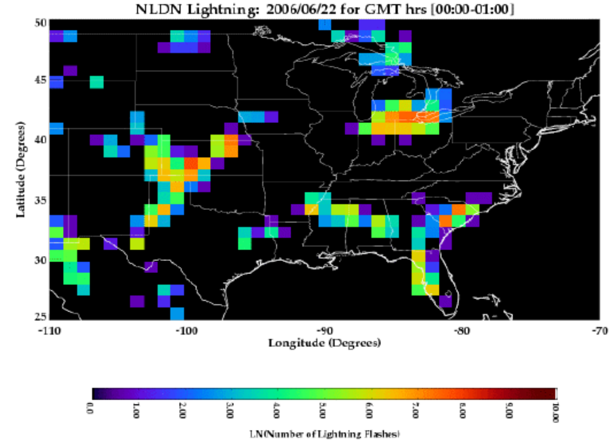


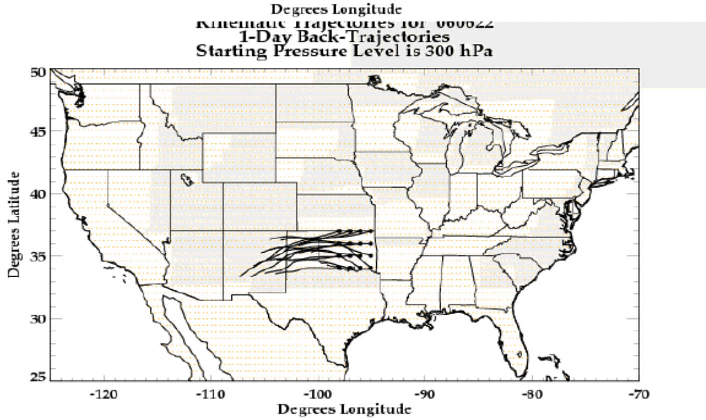
After removal of pixels with 100% cloud cover

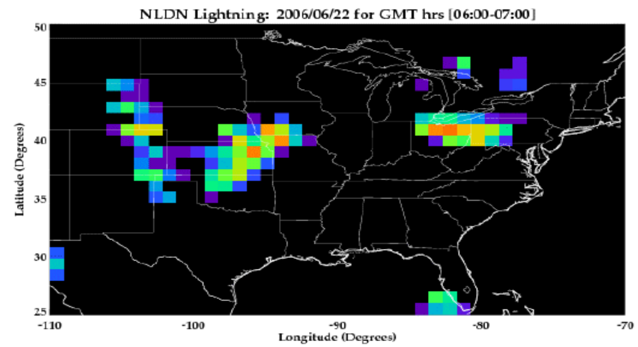


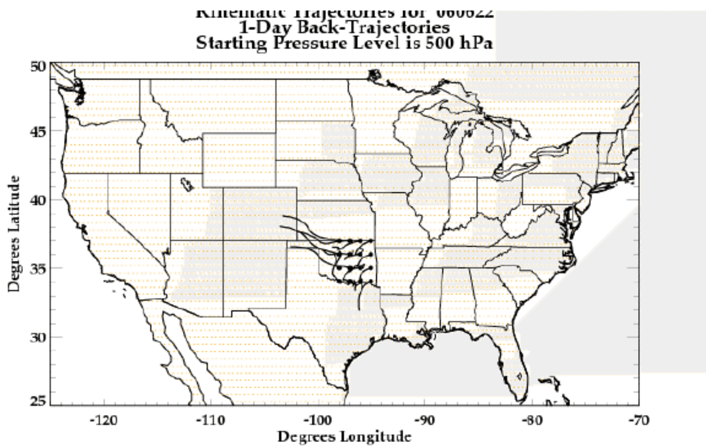
LNO2 on 0.25 x 0.25 degree grid

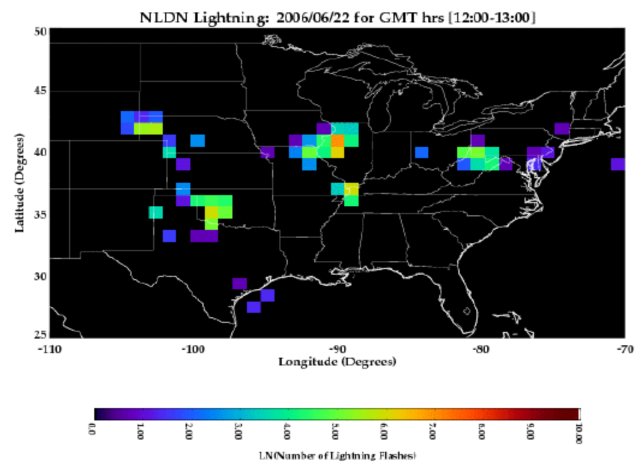

1-Day Back-Trajectories
Starting Pressure Level is 200 hPa
Degrees Latitude
Degrees Longitude


NLDN Lightning: 2006/06/22 for GMT hrs [00:00-01:00]
Latitude (Degrees)
Longitude (Degrees)
LN(Number of Lightning Flashes)


1-Day Back-Trajectories
Starting Pressure Level is 300 hPa
Degrees Latitude
Degrees Longitude


NLDN Lightning: 2006/06/22 for GMT hrs [06:00-07:00]
Latitude (Degrees)
Longitude (Degrees)


1-Day Back-Trajectories
Starting Pressure Level is 500 hPa
Degrees Latitude
Degrees Longitude


NLDN Lightning: 2006/06/22 for GMT hrs [12:00-13:00]
Latitude (Degrees)
Longitude (Degrees)
LN(Number of Lightning Flashes)

Case 2: Calculations

Upstream CG flashes:

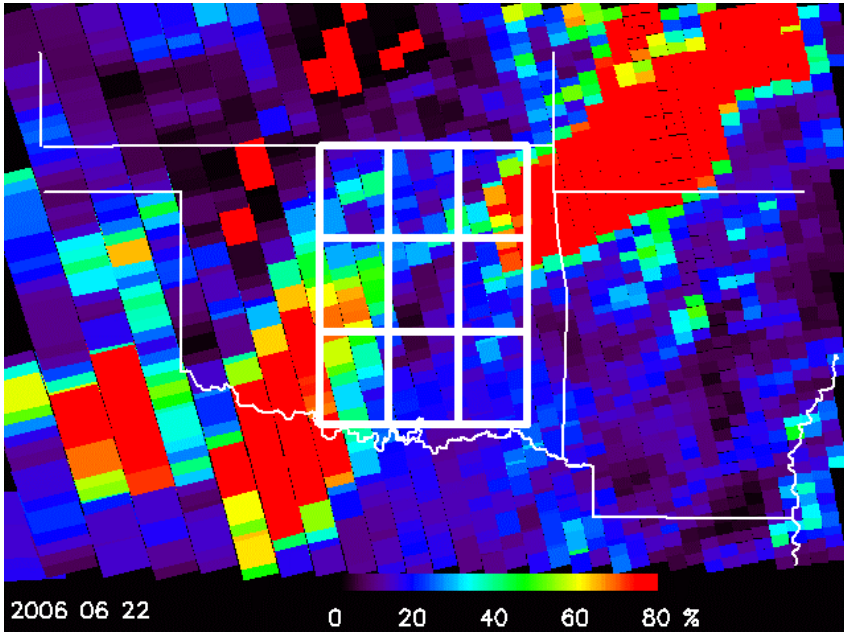
500 hPa	540
300	794
200	1610

Vertical mass weighting and detection efficiency correction yields 868 CG flashes

Scaling up to total flashes using mean IC/CG ratio of 4 for upstream region yields 4339 total flashes

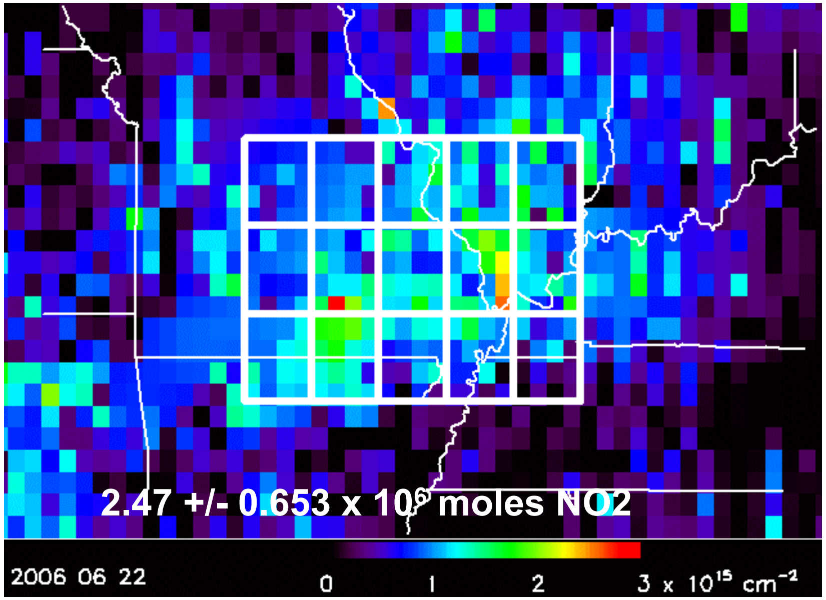
Scaling from NO2 to NOx:
$1.33 \times 10^6 \times 1$ mole NOx/0.3 moles NO2
$= 4.43 \times 10^6$ moles NOx

Estimating moles LNOx per flash:
4.43×10^6 moles NOx/4339 flashes =
997 +/- 389 moles NOx/flash

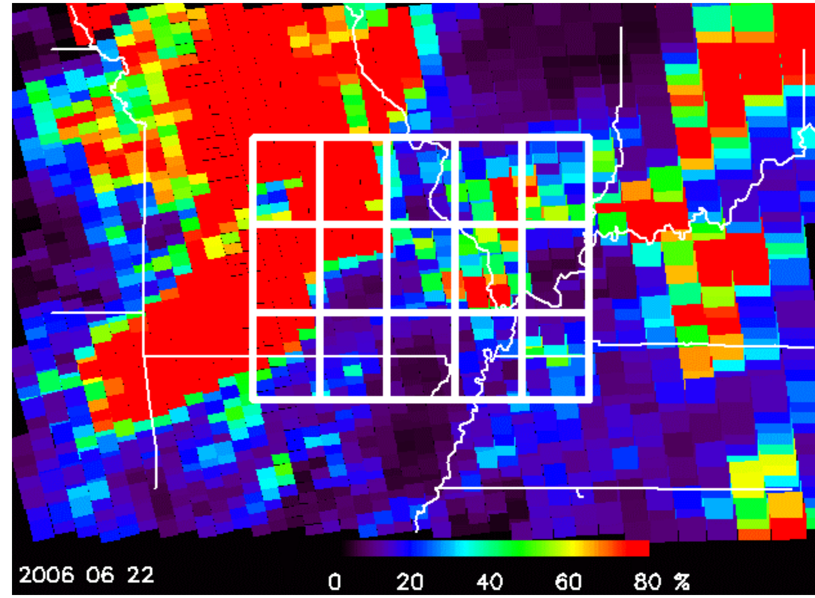


Cloud Cover

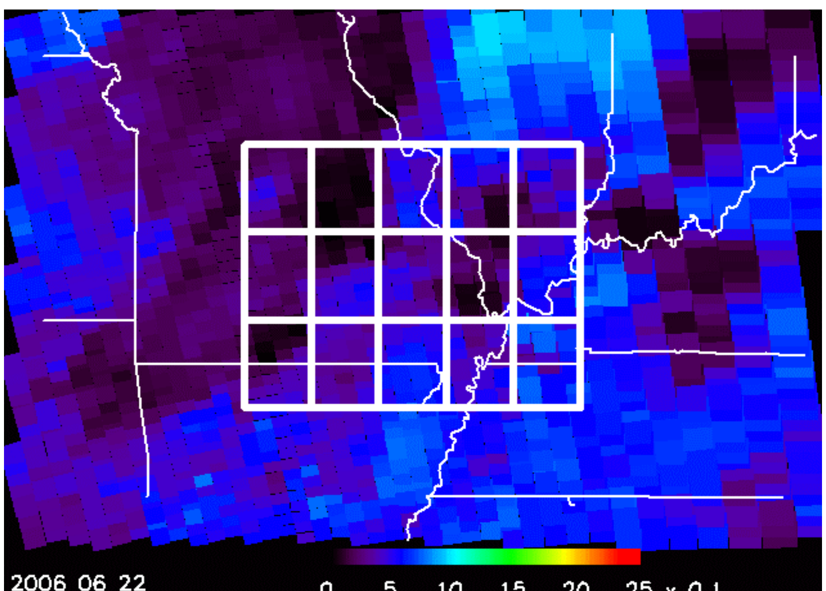
Case 3: June 22, 2006 Missouri



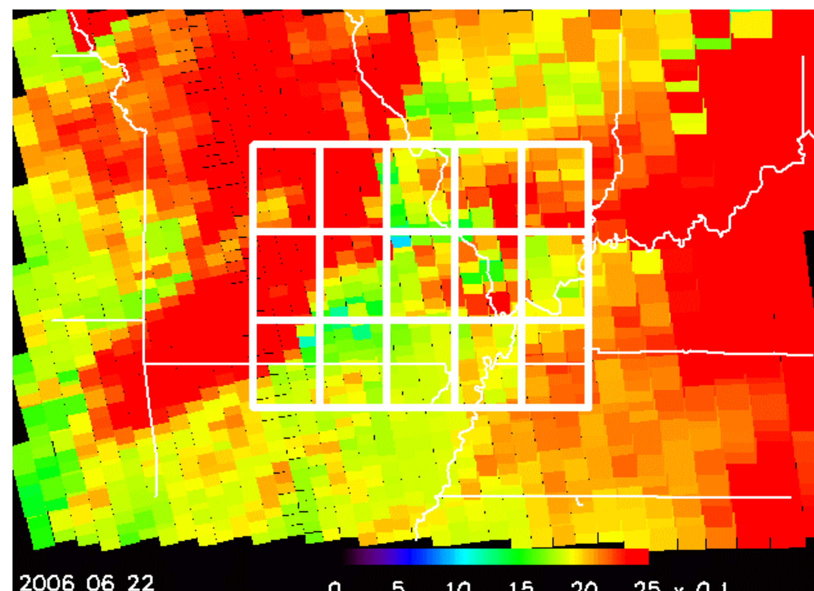
LNO2 on 0.25 x 0.25 degree grid



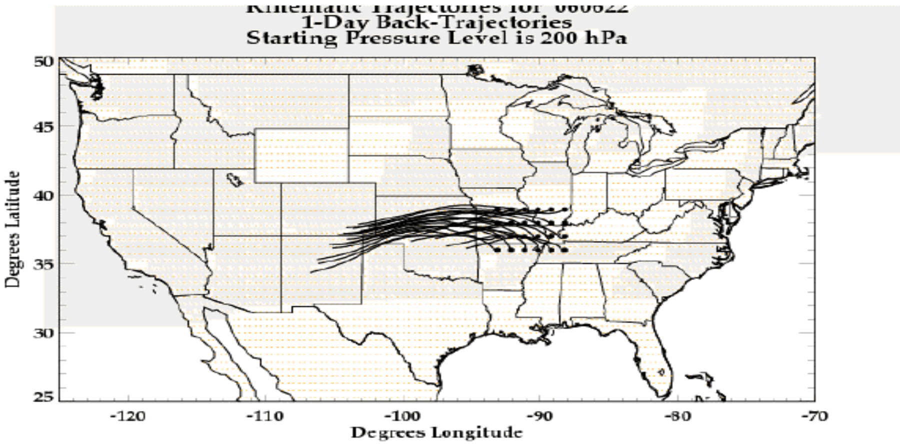
Effective Cloud Fraction



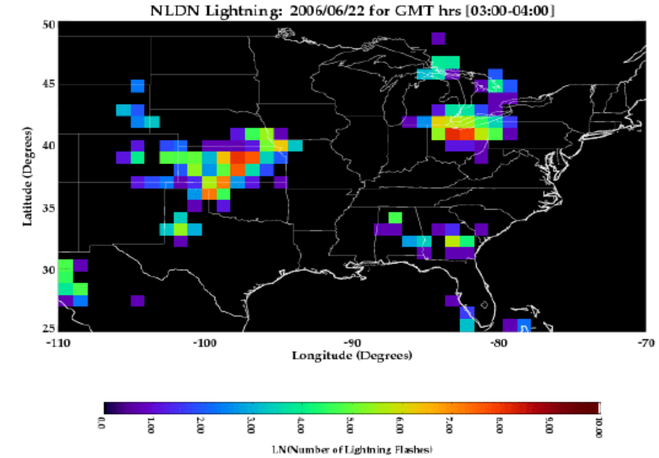
$AMF_{GEOSChem}$



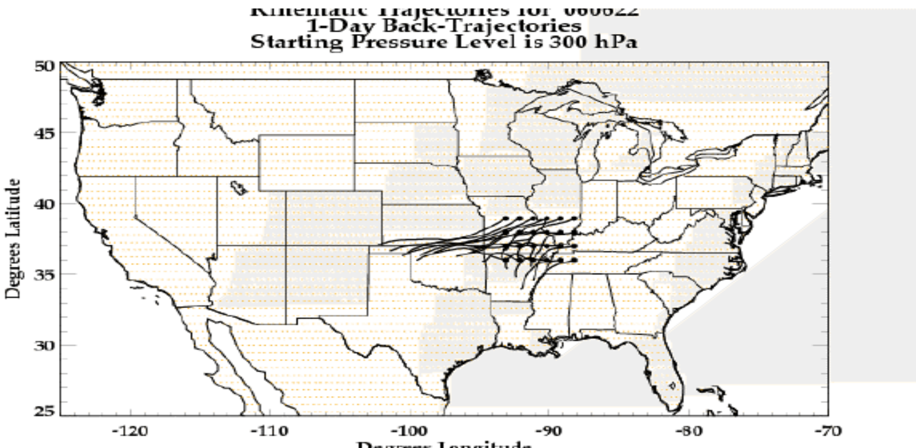
$AMF_{lightning}$



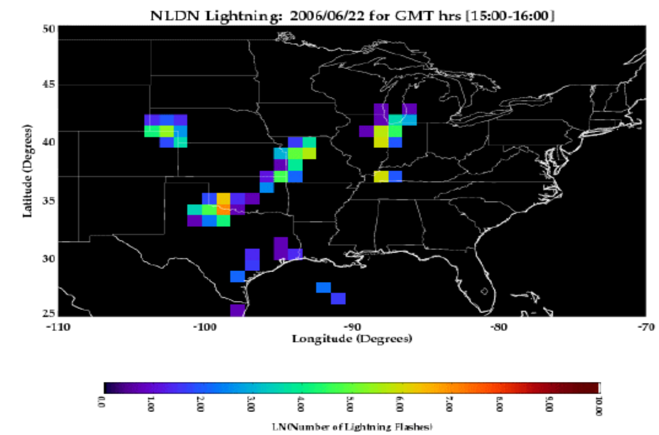
Kinematic Trajectories for 060622
1-Day Back-Trajectories
Starting Pressure Level is 200 hPa
Degrees Latitude
Degrees Longitude



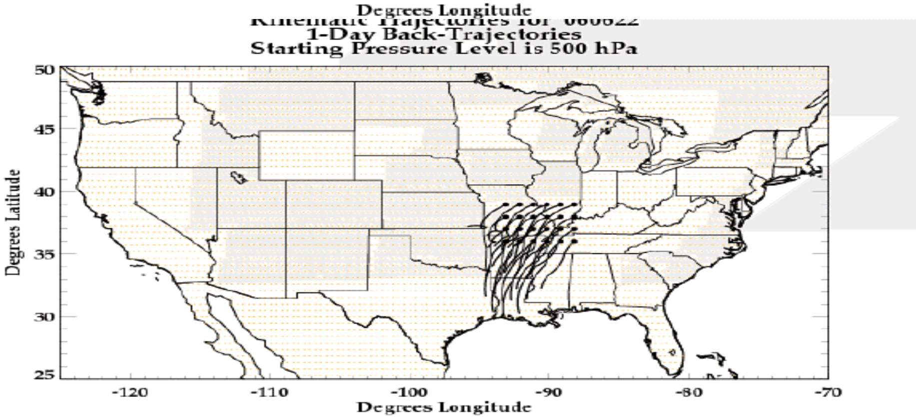
NLDN Lightning: 2006/06/22 for GMT hrs [03:00-04:00]
Latitude (Degrees)
Longitude (Degrees)
LN(Number of Lightning Flashes)



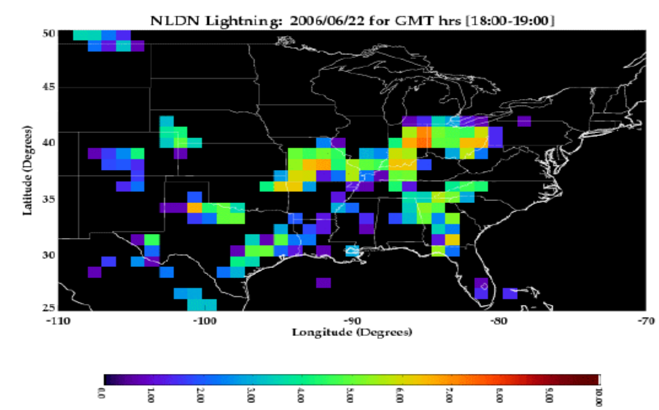
Kinematic Trajectories for 060622
1-Day Back-Trajectories
Starting Pressure Level is 300 hPa
Degrees Latitude
Degrees Longitude



NLDN Lightning: 2006/06/22 for GMT hrs [15:00-16:00]
Latitude (Degrees)
Longitude (Degrees)
LN(Number of Lightning Flashes)



Kinematic Trajectories for 060622
1-Day Back-Trajectories
Starting Pressure Level is 500 hPa
Degrees Latitude
Degrees Longitude



NLDN Lightning: 2006/06/22 for GMT hrs [18:00-19:00]
Latitude (Degrees)
Longitude (Degrees)
LN(Number of Lightning Flashes)

Case 3: Calculations

Upstream CG flashes:

500 hPa	**1824**
300	**2145**
200	**3473**

Vertical mass weighting and detection efficiency correction yields 2413 CG flashes

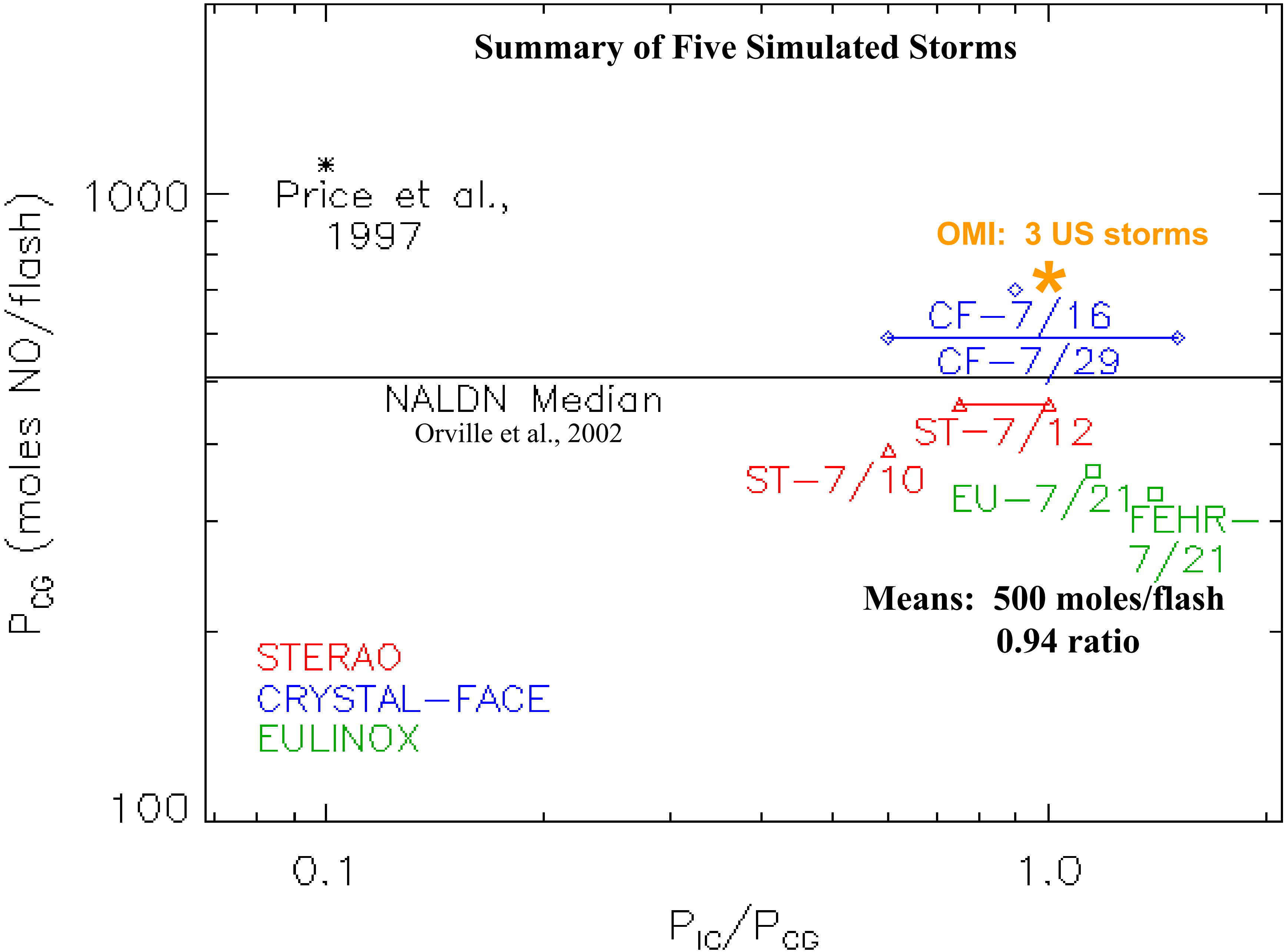
Scaling up from CG to total flashes using mean IC/CG ratio of 4 for upstream region yields 12,066 flashes

Scaling up from NO2 to NOx:
2.47 x 10^6 x 1 mole NOx/0.3 moles NO2
= 8.23 x 10^6 moles NOx

Estimating average moles per flash:
8.23 x 10^6 moles NOx/12066 flashes
= 682 +/- 180 moles NOx/flash

Average over 3 cases:
715 +/- 215 moles NOx/flash

Lightning NO Production Scenarios



Summary

- **Cases of LNOx detected in OMI tropospheric NO2 data over Central U. S.**

- **Employed AMFs appropriate for convective outflow regimes containing LNOx. These AMFs are approximately a factor of 2 larger than those from GEOS-Chem used in the standard retrieval.**

- **Estimates of LNOx production for 3 cases range from 465 to 997 moles/flash (mean = 715 moles/flash with 25-40% OMI retrieval uncertainty). This is at the high end of other recent continental US estimates.**

- **Main uncertainties: radiative transfer in substantial cloud cover, magnitude of tropospheric background NO2 column, IC/CG ratio.**

- **OMI-based estimates, cloud-resolved modeling, and GEOS-Chem simulations all suggest NO production/flash in US > global mean**

Future

- Refine LNOx production estimates for these three cases:
    - Oklahoma case – likely can obtain actual IC/CG ratio from 3-D Lightning Mapping Array data
    - Run trajectories with higher-resolution data from WRF
- Conduct similar analyses with OMI data for Northern Australia and Costa Rica regions:
    - Aircraft data available from SCOUT-O3/ACTIVE and NASA TC4 field experiments
    - Cloud-resolved modeling for specific events from these experiments is underway or will be conducted in the near future
    - Do tropical lightning flashes make less NOx per flash than midlatitude flashes?